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Optical Disk Mastering Using Optical Super Resolution Effect

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ABSTRACT

We propose a new laser lithography technique using the effect of thermal-induced super resolution and demonstrate that the technique can effectively reduce the exposed spot size on the photoresist layer, thus allowing disk mastering toward higher density by using exiting light source and optics. A mask layer, whose nonlinear optical properties result in formation an aperture in high temperature area near to the center of the laser spot, is deposited on the top of the photoresist layer. Usually, the aperture size is much smaller than the laser spot, thus, achieving thermal-induced super resolution. The simulation and experimental results reveal that the line width on the photoresist layer could be shrunk by more than 40% .
KEYWORD: disk mastering, thermal-induced super resolution, lithography

1. INTORDUCTION

In the conventional laser lithography which is used to make optical master disks, the laser beam is directly illuminated on the surface of photoresist layer, so the resulted exposed area or spot size is limited by the optical diffraction limit. The spot size is approximated to 0.82x λ/NA, where λ is the free space wavelength of light source and NA is the numerical aperture of the object lens. There are two main approaches to reduce the spot size: reducing λ and increasing NA. However, the sensitivity of photoresist material depends on the wavelength of light source. NA of the commercial used object lens is 0.9, and the maximum value of NA is 1 in air. Thus, the two schemes in reducing focused spot size are either with some complication or limited performance. The aim of this paper is to demonstrate that using the effect of thermal induced super resolution[1,2] can effectively reduce the spot size on the photoresist layer, thus, allowing disk mastering toward higher density using existing light source and optics.

2. PRINCIPLE

Thermal-induced super resolution is caused by the nonlinear optical property of a metal film.[1,2] By illuminating a metal film with a laser beam, the metal film will melt and the index of refraction of the melting region will yield nonlinear variation locally. Thus, the transmittance of the melting area may be higher than that of other region. Because the Gaussian intensity distribution of the laser beam, so dose the temperature profile of the melting region on the metal film, thus melting region can be well controlled whose size can be much smaller than the focused laser spot size. The intensity distribution of the transmission light should become narrower than that of the incident light. A metal film of Indium is deposited on the photoresist layer, as shown in Fig. 1, the exposed area on the photoresist layer is reduced, thus, forming the finer definition of a line.

3. SIMULATION AND EXPERIMENT

Using Dill's exposure model[3] and Mack's development model[4], the thermal-induced super resolution effect caused by the metal layer on a photoresist layer was modeled. In the simulation, λ is 442 nm and NA is 0.5, and metal layer used in this work is GeTeSb, a DVD-RAM recording layer. Experimentally, a line is laterally exposed by a laser-exposing machine on a specimen with the structure shown in Fig. 1. Before development, the metal layer must be removed by some etching solution. After development, the exposed region was removed and formed a linear groove. The experimental parameters are listed in Table 1.

4. SIMULATION RESULTS

The simulated results of exposure and development of mastering process without and with the metal layer are shown in Figs. 2 and 3, respectively. After exposure, the distributions of the PAC (photoactive compound) concentration are shown in

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Fig. 2. The PAC concentration is normalized so that 1 and 0 represents unexposed and completely exposed, respectively. Figs. 2(a) and 2(b) are the 2D and 3D distributions of the PAC concentration without the metal layer. Owing to the Gaussian intensity distribution of the laser beam and the standing wave effect, the distributions of the PAC concentration in the r and z direction are a Guassian distribution and sinusoidal profile, respectively. With the metal layer, the 2D and 3D distributions shown in Figs. 2(c) and 2(d) reveal that the standing wave effect still exits in the z direction, but the Guassian distribution in the r direction is distorted by the thermal-induced super resolution. After development, the cross-sectional views of the photoresist layer are shown in Fig. 3(a) without, Fig. 3(b) with 5 nm, and Fig. 3(c) with 10 nm metal layer, respectively. The black regions denote the residue photoresists. To simplify the description, we define the space at the bottom and the half depth of the groove as $W_{interface}$ and linewidth, respectively, as shown in Fig. 4. As shown in Fig. 3(a), $W_{interface}$ is about 2.1 nm without the metal layer, and the angle of the slope at the edge of the groove is about 30°. According to the simulation, 5 and 10 nm metal layers can form an aperture of the diameter of 0.7×spotsize and 0.5×spotsize respectively. The results imply that the metal layer yields optical super resolution effect. Consequently, as the thickness of mask layer increases from 0 to 10 nm, $W_{interface}$ shrinks from 2.1 to 1.3 um with the same angle at the edge of the groove, as shown in Figs. 4(b) and (c). As the angle does not vary with the shrinkage of $W_{interface}$, the linewith will decrease with $W_{interface}$. The experiment results demonstrate that thermal-induced super resolution effect can effectively shrink the linewidth of the groove.

However, it is very difficult to measure the size of aperture in real-time, so we examined influences of metal layer thickness and aperture size on the profile of photoresist layer in order to compare with the experimental results. The relations among the metal layer thickness, aperture size, $W_{interface}$, and the angle of the edge are depicted in Fig. 5. The three dashed lines represent the results of completely super resolution effect to result in the shrinkage of the $W_{interface}$ with same angle. The solid lines (a) and (b) represent the influences of the metal layer thickness and aperture size on the profile of the photoresist layer, respectively. From solid line (a), it is found that the decreasing of $W_{interface}$ mainly arises from the increasing of metal layer thickness. On the contrary, when the thickness of the metal layer is fixed, the variation of the aperture size can only result in altering the angle of the edge, as shown in solid line (b), implying that the optical super resolution is the combination of absorption effect, and shading effect.

5.EXPERIMENTAL RESULTS

Using the structure shown in Fig. 2, the shrinkage of the linewidth can be observed easily. In Fig. 6, the linewidth shrinks from 2.5 um, which is the limit of exposure machine, to 1.4 um as the thickness of Indium film increases form 0 to about 40 nm. To make sure the effect is caused by the super resolution, we further increase the thickness of Indium film. When the thickness is more than 40 nm, the linewidth does not shrink, but broaden, which may be caused mainly by absorption effect, as shown in Fig. 7 as the Indium film is too thick to be melted by laser beam. When laser beam passes through Indium film, the absorption effect no longer shrinks the spot size as optical super resolution. Experimental results demonstrate that the linewidth can only be reduced by the optical super resolution effect.

We then used SEM to make more detail observations on the microstructures of the groove. The top view is shown in Fig 8, where (a) without, (b) with 10 nm, and (c) with 30 nm Indium film, respectively. Most notably, the fluctuation of line edges gradually increase from 100 to 300 nm with the shrinkage of linewidth. Because the linewidth depends on the thickness of Indium film, the fluctuation must be influenced by the thickness of Indium film. As the thickness of Indium film increases from 15 to 36 nm, the grain size of the film will rapidly grow from 20 to about 100 nm, as shown in Fig. 9. In melting state, the larger the grain of film is, the rougher the edge of melting region is, as shown in Fig. 10. The sharpness of line is mainly determined by the grain size of Indium film.

In the previous simulation results, we used the cross-sectional profile of phototresist layer to observe the effect of super resolution. To compare with the results, we also used SEM to observe the cross-sectional profile of phototresist layer, as shown in Fig. 11. When $W_{interface}$ decreases from 2.1 to 1.7 um caused by the increase of the Indium film, the angle of the groove edge is almost the same. However, as $W_{interface}$ decreases from 1.7 to 1.368 um, the angle of the groove edge changes from 33° to 25°. From the simulation results shown in the curve c of Fig 3, we can extrapolate that the shrinkage of the linewidth is due to the absorption effect caused by the increase of Indium film and the change of the angle is the consequence of failing to form an aperture in the thick Indium film.

6. Conclusion

The effect of thermal-induced super resolution was applied the disk mastering process to greatly decrease the exposed area of photoresist using the existing optics. From simulation and experiment, the linewidth more than 40% less

than the diffraction limits defined by the laser-exposing machine limit was demonstrated. Further reductions of linewidths are feasible when shorter wavelength light source and higher NA optics are used in mastering system.

7. Reference

1) K. Yasuda, M. Ono, K. Aratani, A. Fukumoto, M. Kaneko: Jpn. Jap. Apl. Phys. 32, 5210(1993)
2) Jia-Reuy Liu and Hang-Ping David Shieh, Jpn. Jap. Apl. Phys. 37, 516(1998)
3) F. H. Dill et al., IEEE. Trans. Electron Device, ED-22, 445(1975)
4) C. A. Mark: Solid-state Science and Techol, 134 No. 1, 148 (1978)
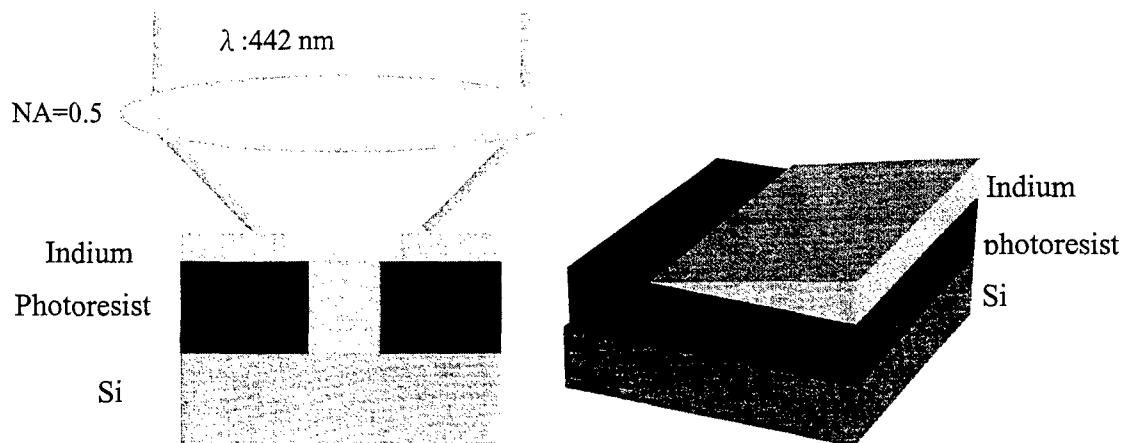
Fig. 1. A metal layer (Indium) is deposited on the photoreisit layer

Table 1. The experimental parameters

| Materiel of the mask layer	Indium	
Thickness of the mask layer (nm)	0~30	
Photoresist	AZ 6112	
thickness of the photoresist layer (nm)	150-350	
development solution	AZ 300	
etching solution	$HF:H_2O_2:H_2O=4:1:1$	
Evaporation Condition		
Pressure (torr)	10^{-5}	
Current (A)	125	
Exposure Condition		
Wavelength (nm)	442	
NA	0.5	
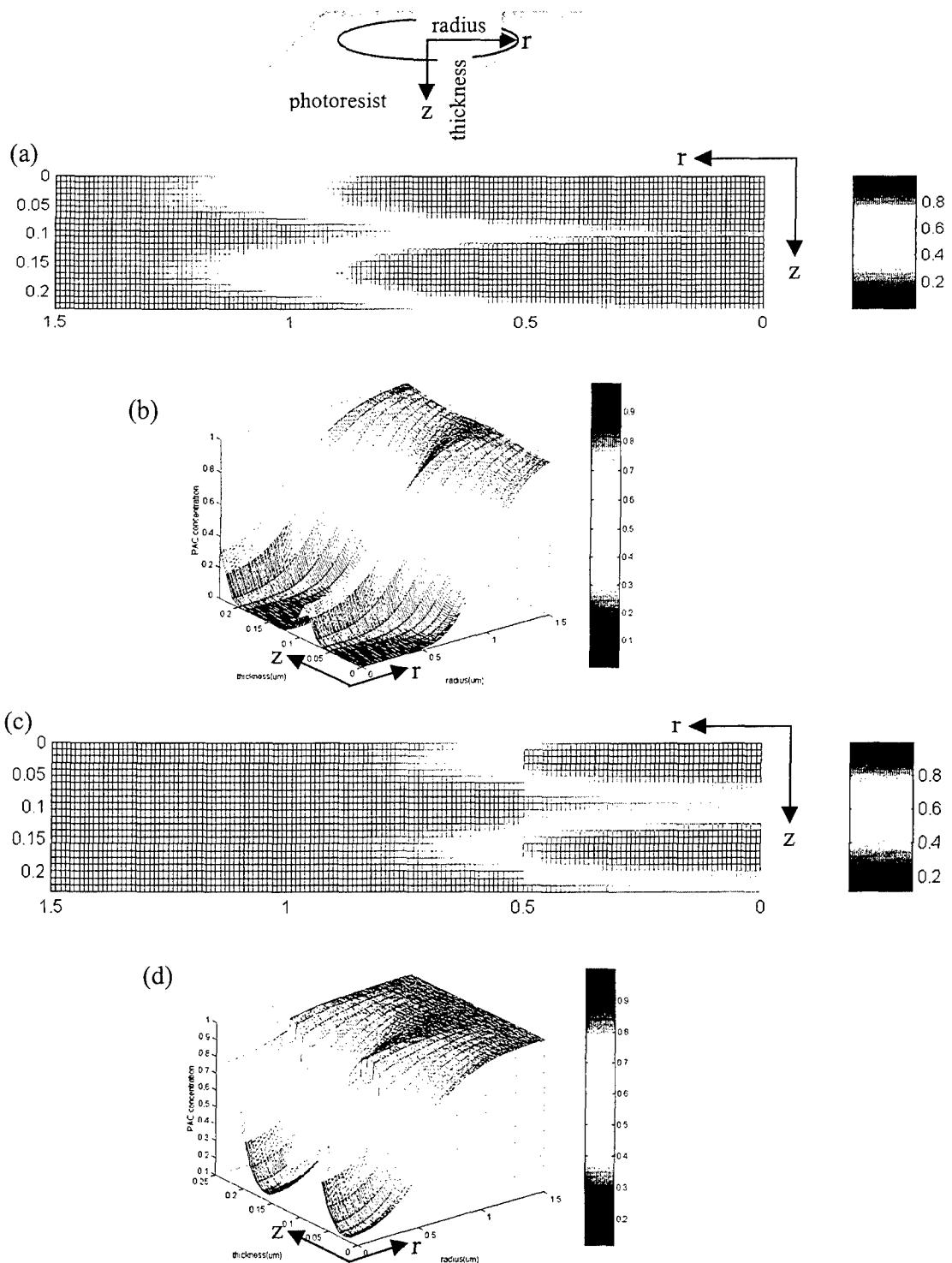
Fig. 2 After exposure, the distribution of PAC concentration on the photoresist layer. (a) 、 (b) without the mask layer, (c) 、 (d) with the mask layer

(a) without mask layer
2.0 um

(b) mask layer：5 nm
aperture：0.7 spot size
1.7 um

(c) mask layer：10 nm
aperture：0.5 spot size
1.3 um
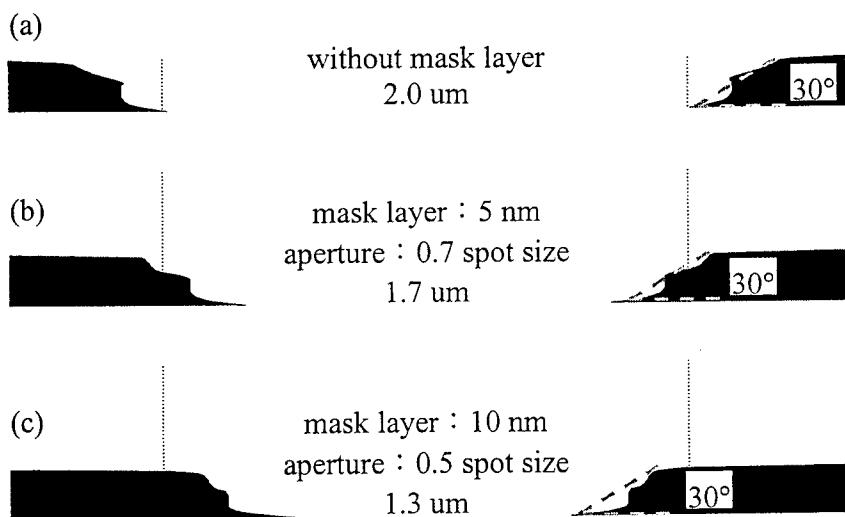
Fig. 3 After development, the profile of photoresist layer. (a) without, (b) with 5 nm, and (c) with 10 nm mask layer

linewidth
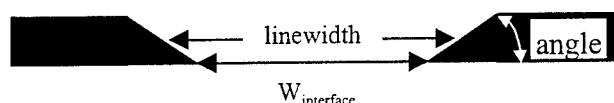
angle

$W_{interface}$

Fig. 4 Definition of $W_{interface}$, linewidth, and angle

: angle 30°

--- : angle 27°

--- : angle 24°
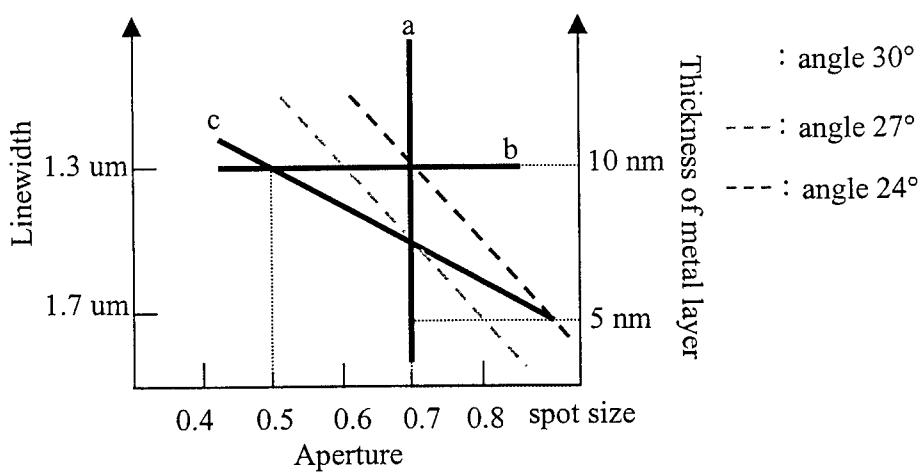
Fig. 5 Relationship among the metal layer thickness, aperture size, $W_{interface}$ and the angle of the edge

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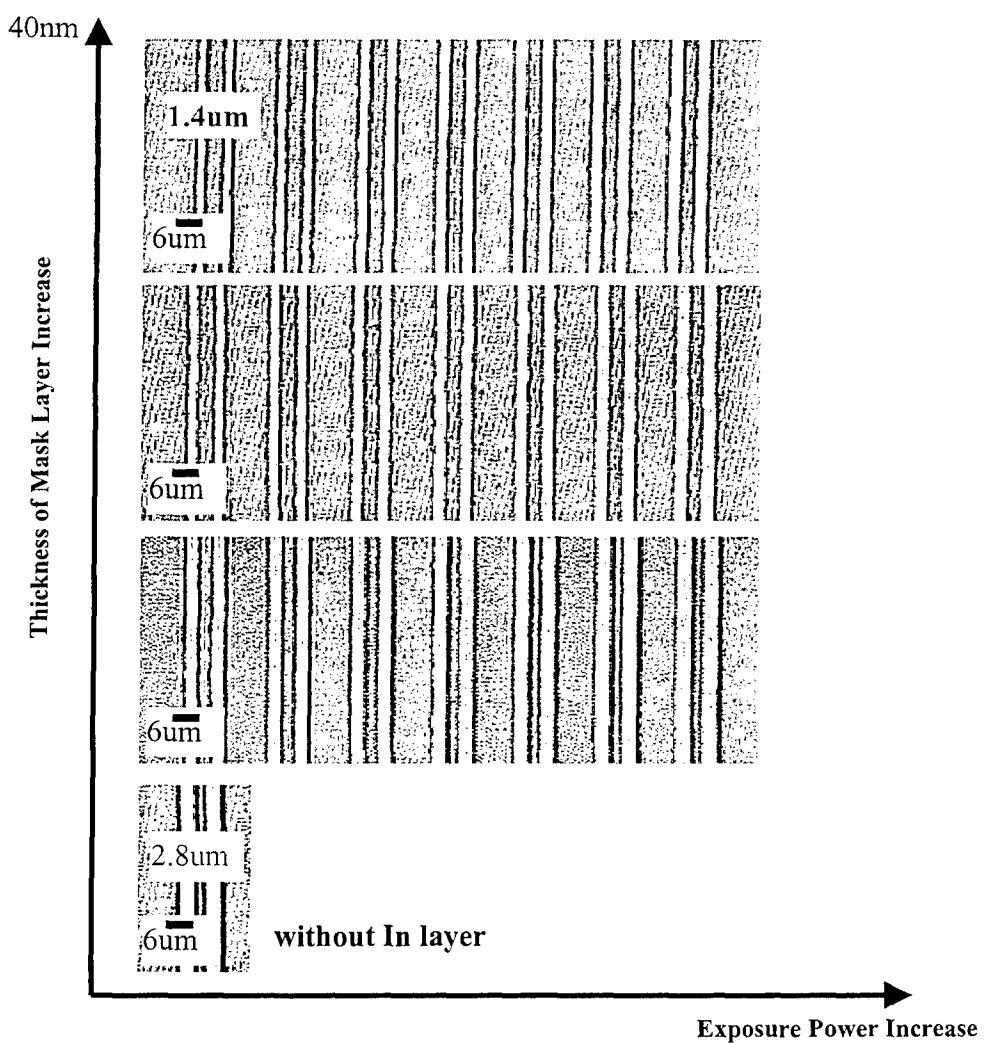
Fig. 6 Linwidth as functions of the thickness of Indium film and different exposure power
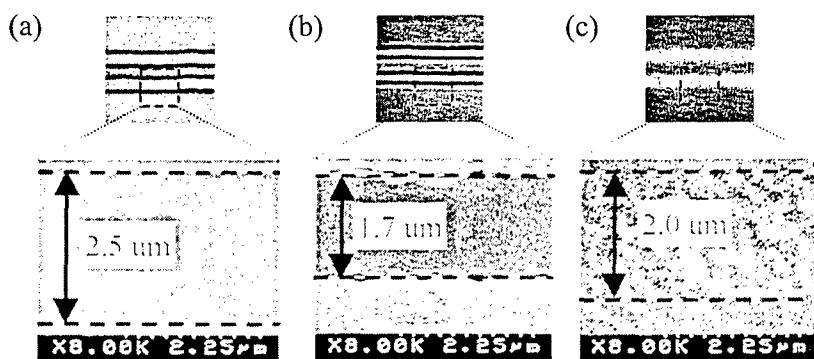

Fig. 7 The difference between super resolution effect and absorption effect. (a) without the Indium film, (b) result of super resolution, and (c) result of absorption effect

(a)

(b)

(c)
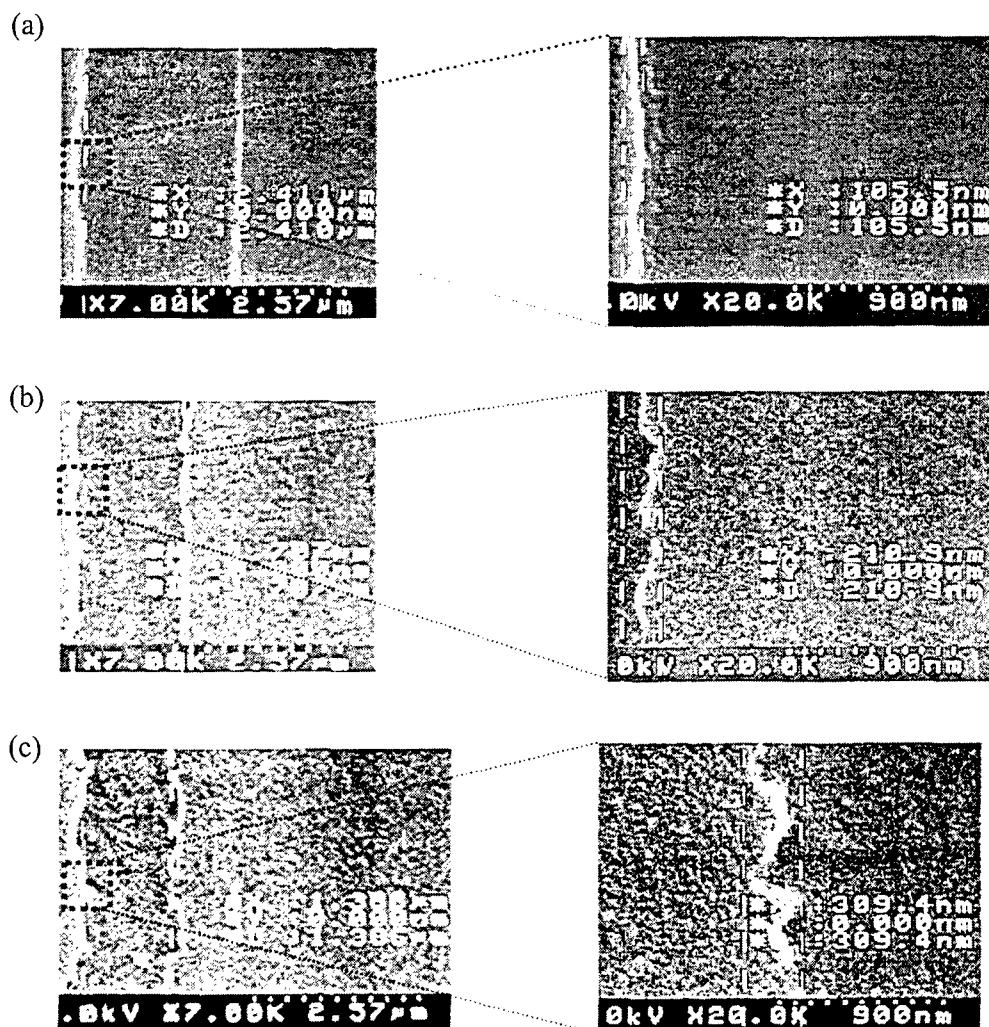
Fig. 8 The fluctuations of the line edge. (a) Without, (b) with 7nm, and (c) 30nm Indium film

15 nm

35 nm
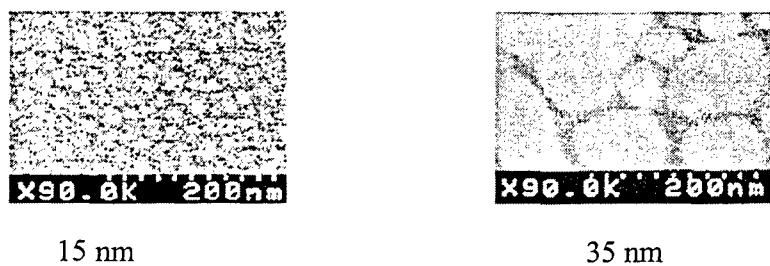
Fig. 9 SEM micrographs showing different grain size of the Indium films of different thickness

The melting region formed on the inhomogeneous film

grain

The ideal melting region formed on the homogenous film which the grain size approaches to 0nm
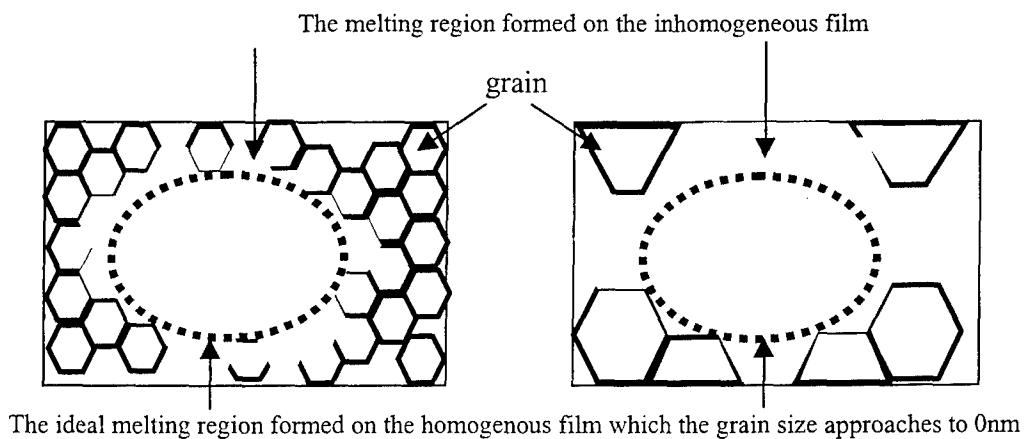
Fig. 10 The influence of grain size on the area of melting region

(a)

(b)

(c)
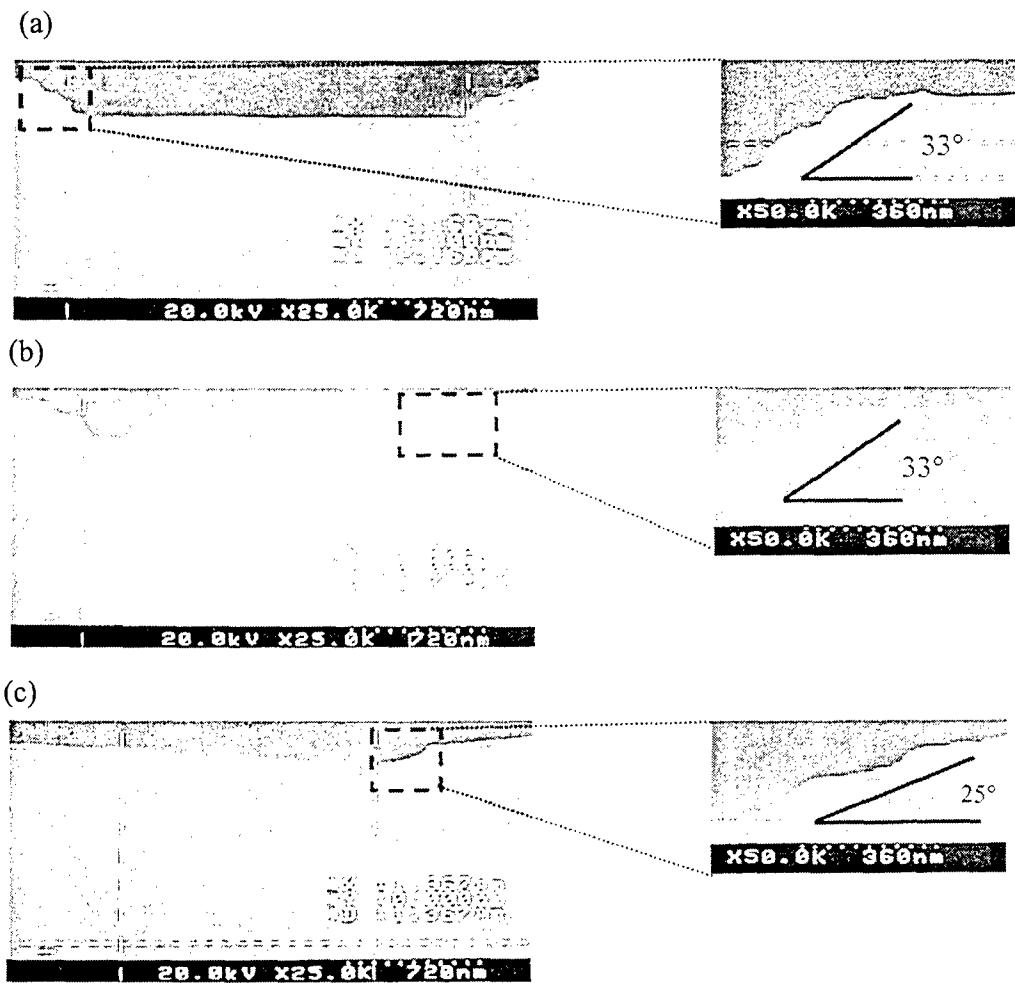
Fig. 11 After development, the cross section of photoresist layer. (a) without, (b) with 7 nm, and (c) with 30 nm Indium film